UMTS/GSM MULTI MODE RECEIVER DESIGN

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ABSTRACT

With the objective of designing a transceiver IC for multi mode operation, the RF requirements for the whole transceiver from antenna to baseband are derived from the UMTS- and GSM-standards. The RF-parameters found for the overall system are broken down to building block level. The boundary conditions for the transceiver IC were defined using specifications of currently available external components. The work presented here focuses mainly on the receiver design, but in case of UMTS-FDD it also takes the interference from the transmitter into account. Multi mode operation of the transceiver could be obtained by re-using most of the building blocks. Others like front end SAW-filters can neither be integrated nor re-used.

1. INTRODUCTION

The demand for higher data rates in mobile communication led to the introduction of third generation mobile communication systems, often referred to as 3G. Of course during the start the coverage of 3G networks will be far from complete. The subscriber who is used to the good coverage provided by 2G networks will not be satisfied with less. Hence, during the transition from 2G to 3G the handsets have to be capable of working in both networks, combining the high data rates provided by 3G wherever available and the good coverage of 2G elsewhere. In Europe the according 3G standards are UMTS FDD and UMTS TDD. The 2G standards are EGSM and DCS 1800. The RF-aspects are defined in the according 3GPP and ETSI specifications [1], [2] and [3]. The GSM standard is well established and various chip sets are available. While the UMTS FDD network is currently being built up in Europe, TDD is to follow shortly after, so that multi mode phones and components become necessary. The RF requirements for the FDD mode have already been investigated [4]. The work presented here has its focus on multi mode operation.

2. RF-REQUIREMENTS

Most of the RF relevant parameters can directly be derived from the GSM- and UMTS-standards. These RF parameters have to be distributed among the transceiver IC and external components. Besides that some aspects of multi mode operation have to be considered.

2.1. UMTS-requirements

For the UMTS FDD and TDD mode a set of receiver test cases is defined, in which a Bit Error Rate (BER) of 0.001 must not be exceeded. All these test cases use a DL reference measurement channel (12.2 kbps). The maximum input power test case for UMTS includes the presence of an interfering signal that can be regarded as noise. This interfering signal uses the same frequency but other spreading sequences and can not be eliminated before the digital baseband. The linearity requirements must be met for the interferer plus the useful part, while the voltage of the desired part of the signal has to be amplified to the set-point. Since the BER of 0.001 has to be met for this test case it also yields a Signal to Noise Ratio SNR that guarantees a BER $\leq$ 0.001.With this SNR and the minimum input power the required system noise figure NF can be estimated without detailed analysis of the baseband algorithms. The Adjacent Channel Selectivity (ACS) and the in band blocking test case for UMTS specify the baseband filter characteristic and the phase-noise performance of the RX-VCO. IIP3 is defined in the intermodulation test case and IIP2 can be calculated from the blocking at 15 MHz offset in case of UMTS TDD and from self blocking in case of UMTS FDD. The RF-parameters listed below in Table 1 refer to the antenna connector of the user equipment. Instead of power gain the voltage amplification A_V is listed, since the input impedances of the baseband stages can be in the range of some MΩ.

	SNR_{min}	NF_{max}	$IIP2_{min}$	$IIP3_{min}$
FDD	-18.9 dB	9.6 dB	8 dBm	-21.3 dBm
TDD	-6 dB	9.2 dB	8 dBm	-20.9 dBm
	P_{min}	P_{max}	$A_{V,min}$	$A_{V,max}$
FDD	-117 dBm	-25 dBm	22 dB	95 dB
TDD	-105 dBm	-25 dBm	10 dB	83 dB

Table 1: RF-requirements for UMTS

2.2. GSM-requirements

For EGSM and DCS 1800 some test cases are defined differently. The cochannel interference test case directly yields the SNR, that is necessary to achieve the required BER. The specified Carrier to Interferer Ratio CIR = 9 dB is the same as the required SNR for most of the other test cases. IIP2 is calculated from the AM suppression characteristics. System noise figure NF, VCO phase-noise, IIP3, and filter performance are calculated similar to their UMTS-equivalents. The RF-parameters for EGSM and DCS 1800 are listed in Table 2. They also refer to the antenna connector of the device.

	SNR_{min}	NF_{max}	$IIP2_{min}$	$IIP3_{min}$
EGSM	9 dB	10 dB	43 dBm	-18 dBm
DCS 1800	9 dB	10 dB	43 dBm	-18 dBm
	P_{min}	P_{max}	$A_{V,min}$	$A_{V,max}$
EGSM	-102 dBm	-15 dBm	-7 dB	80 dB
DCS 1800	-102 dBm	-23 dBm	1 dB	80 dB

Table 2: RF-requirements for GSM

2.3. Frequency separation

The receiver that is to be designed has to support different mobile standards in different frequency bands. The separation of the different frequency bands is done by a combination of front end switches and bandpass filters. For EGSM, DCS 1800 and UMTS TDD single bandpass filters are sufficient. In the UMTS FDD mode the receiver and the transmitter work simultaneously in different frequency bands using the same antenna. This leads to very high demands on RX-TX separation. The most stringent requirements for RX-TX separation can be found in the reference sensitivity test case of the receiver. The wanted signal is –117 dBm while the output signal of the transmitter is +24 dBm [1]. Taking duplexer losses of 3 dB for RX and 1.5 dB for TX into account the received signal is 145.5 dB below the transmit signal. Hence, receiver and transmitter can not be regarded independently from each other. A possible solution for the problem of self inflicted blocking is shown in Figure 1.

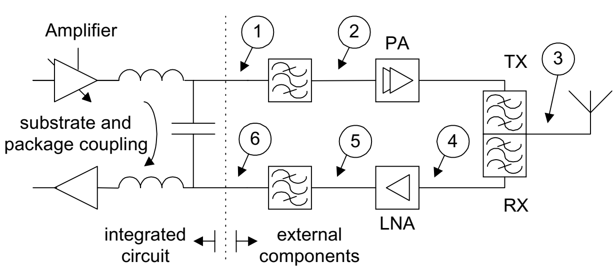

Figure 1: Filtering in the FDD mode

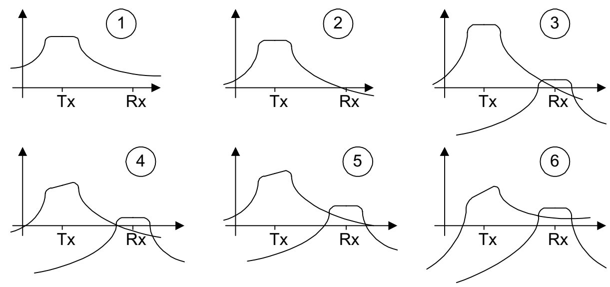

Figure 2: Signal levels

	1. PGA out	2. Filter out	PA out	3. Antenna
Signal TX	+1 dBm	-2.5 dBm	25.5 dBm	24 dBm
N @ f_{RX}	-147 dBm/Hz	-174 dBm/Hz	-136 dBm/Hz	
	3. Antenna	4. LNA in	5. Filter in	6. Amp. in
Signal RX	-117 dBm	-120 dBm	-105 dBm	-109dBm
Signal TX	24 dBm	-23 dBm	-8 dBm	-38 dBm
N @ f_{RX}	-174 dBm/Hz	-174 dBm/Hz	-157 dBm/Hz	-160.7 dBm/Hz

Table 3: Signal-, noise- and blocker-level

The TX signal itself can be regarded as a blocking signal that can drive the LNA into saturation while its noise sidebands interfere with the RX signal. These noise emissions in the RX-band are decreased by a TX-bandpass filter between the PA driver and the PA and again by a duplexer at the antenna. So the thermal noise and not the TX–noise is the limiting factor for the first RX-LNA. The package and substrate coupling set limits on the amplification that can be realized on chip. Therefore, an external LNA is employed, followed by an RX-bandpass filter that decreases the TX blocker. In Table 3 the signal-, noise-, and blocker-levels along the RX- and TX-path are listed. Some typical specifications for external components that are currently available can be found below in Table 4.

Duplexer		
Insertion loss	RX-Ant @ f_{RX}	TX-Ant @f_{TX}
	$\leq$ 2.4 dB	$\leq$ 1.5 dB
Isolation	RX-TX @ f_{RX}	RX-TX @ f_{TX}
	$\geq$ 47 dB	$\geq$ 49 dB
TX-Filter		
Insertion loss	IL @ f_{TX}	Att @ f_{RX}
	$\leq$ 3.5 dB	$\geq$ 35 dB
RX-Filter		
Insertion loss	IL @ f_{RX}	Att @ f_{TX}
	$\leq$ 3.7 dB	$\geq$ 30 dB
PA and LNA		
Gain PA (TX)	Gain LNA (RX)	NF LNA (RX)
28 dB	15 dB	$\leq$ 2 dB

Table 4: Specifications of external components

Figure 3 shows the resulting re-configurable front-end for multi-mode operation with some external components. The transceiver IC provides a common TX path for all supported modes. Since the requirements to the PA are quite different for the individual modes each mode requires its own PA. The selection has to be done by front end switches. In the RX path each mode has its own LNA on the IC, tailored to the specific requirements.

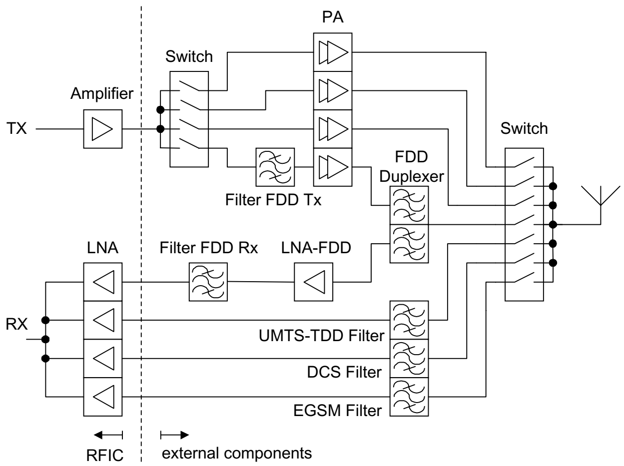

Figure 3: Re-configurable front end

The overall RF-parameters listed in Table 1 and 2 have to be distributed to the RFIC and external components. For UMTS TDD, EGSM and DCS 1800 front end losses of 3 dB minimum and 4 dB maximum are assumed. These front end losses are caused by the front end switch, band filters, lines and matching elements. For the UMTS FDD mode relevant parameters of external components are listed in Table 4. With the aid of these external components the RF-parameters for the transceiver-IC can be defined. The final RF-parameters for the IC are listed in Table 5. The relatively high noise-figure NF_{max} for the FDD mode can be explained with the external LNA.

	NF_{max}	$IIP2_{min}$	$IIP3_{min}$
UMTS FDD	19.6 dB	18 dBm	-11 dBm
UMTS TDD	5.2 dB	5 dBm	-23.9 dBm
EGSM	6 dB	40 dBm	-21 dBm
DCS 1800	6 dB	40 dBm	-21 dBm

	P_{min}	P_{max}	$A_{V,min}$	$A_{V,max}$
UMTS FDD	-121 dBm	-28 dBm	25 dB	99 dB
UMTS TDD	-109 dBm	-28 dBm	13 dB	87 dB
EGSM	-106 dBm	-18 dBm	-4 dB	84 dB
DCS 1800	-106 dBm	-26 dBm	4 dB	84 dB

Table 5: RF parameters for the multi mode RFIC

3. RECEIVER ARCHITECTURE

The direct conversion receiver (DCR) has become standard in most GSM phones and is ideally suited for multi-mode applications. The main advantages over other architectures are the simple frequency planning and the possibility of high scale integration [5]. Channel filtering can be done at baseband frequency. For multi mode operation these baseband filters have to be tunable in their cutoff-frequency. Tunable filters have already been successfully implemented [6], [7]. An inherent problem of DCRs is the DC-offset. Self mixing of the LO and non constant envelope blockers are transferred to DC or baseband frequencies, respectively. Since the baseband stages work at frequencies starting at 0 Hz this becomes a problem. Different approaches to solve this problem were found [5].

Independent from the level of the input signal the useful part of the output signal has to be amplified to a setpoint of approximately 50 mVpp depending on the chosen architecture. The gain values of the different PGA stages have to be set accordingly. Besides the useful signal there can be interfering signals that have to be eliminated in the digital baseband. In the UMTS FDD maximum input power test case the total input power is –25 dBm of which only –44 dBm are useful data [1]. This signal can only be detected by despreading in the digital baseband. In GSM mode in band blockers can be higher than the signal itself even at the end of the RX-chain. The detection how much of the input signal is useful data can only be done by the digital baseband. Hence, the gain control has to be realized there. For the elimination of blockers with different frequency offsets from the desired channel and different levels channel filtering is required. The first filter stage in the DCR shown in Figure 3 is a passive filter stage at the output of the mixer. It can be regarded as an RC-filter with a fixed cutoff frequency of f_{3dB} = 5.7 MHz. This stage is followed by a cascade in which PGA stages and filter stages alternate. The two 2nd order filter stages form a 4^{th} order butterworth lowpass filter with tunable cutoff frequency. For the UMTS mode it is set to f_{3dB} = 2.2 MHz, for GSM it is f_{3dB} = 200 kHz. Butterworth characteristic was chosen, because it offers a good trade-off between group delay distortions and selectivity. The topology with alternating PGAs and filter blocks was chosen, because it offers a good trade-off between noise performance at reasonable power consumption, linearity and filter performance. At the output of every PGA the blocker level is amplified close to the maximum output swing and then attenuated in the following filter-stage.

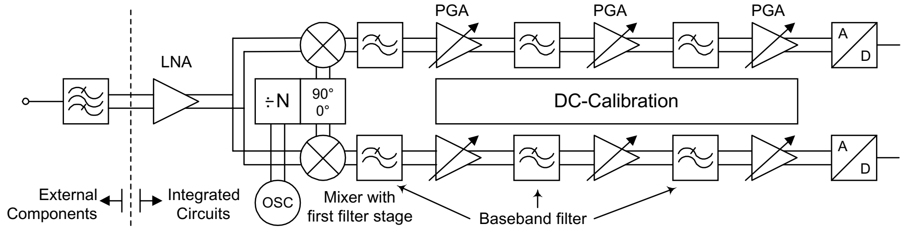

Figure 4: Block diagram of the direct conversion receiver

4. VCO REQUIREMENTS

Reciprocal mixing of blocking signals in adjacent channels with the noise sidebands of the LO result in additional noise at baseband frequency. Hence, the blocking- and adjacent channel selectivity test cases set the limits on the VCO phase-noise. Figure 5 depicts the phase-noise requirements of the different modes. The EGSM mode makes the highest demands on the RX-VCO.

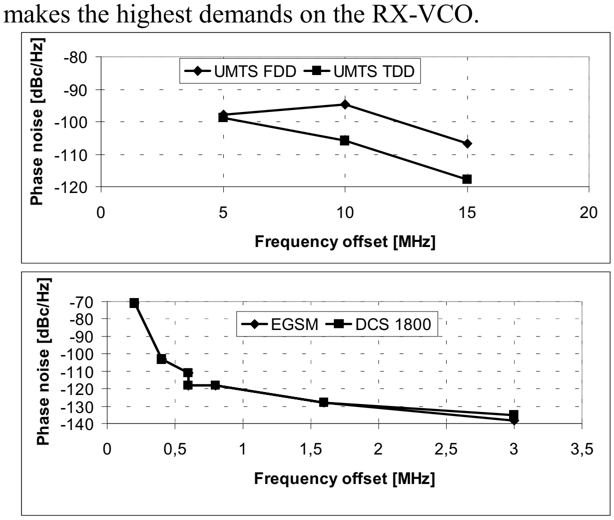

Figure 5: Phase-noise requirements for RX-VCO

For EGSM the required LO-frequency is between 925 MHz and 960 MHz. For DCS 1800, UMTS FDD and UMTS TDD it is between 1805 MHz and 2170 MHz. The actual VCO frequency range is 3160 MHz to 4340 MHz. For EGSM the VCO frequency is divided by 4 in a scaler that also provides a phase shift of 90 degrees for the I- and Q-channel of the QAM-demodulator. In all other modes the VCO frequency is divided by 2.

5. CONCLUSION

A system design for the receiver of a multimode transceiver-IC has been introduced. The boundary conditions for the IC have been defined with the aid of external components that are currently available. In the RX-path all building blocks, except for the LNA, are re-usable for all modes. The baseband lowpass filter is tunable in its cutoff frequency between 200 kHz and 2.2 MHz. The LO with a frequency range from 3160 MHz to 4340 MHz covers all supported modes. For EGSM operation the LO-frequency is divided by 4, for all other modes the scaling factor is 2. The RFIC described in this work is currently being realized.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] 3rd Generation Partnership Project (3GPP) "UE Radio Transmission and Reception (FDD), technical specification 25.101 V5.2.0", March 2002

[2] 3rd Generation Partnership Project (3GPP) "UE Radio Transmission and Reception (TDD), technical specification 25.102 V5.0.1", March 2002

[3] European Telecommunications Standards Institute (ETSI) "Digital cellular telecommunications system (Phase 2+); Radio transmission and reception (GSM 05.05 v8.4.0)", May 2000

[4] P. Madsen, et al., "RF Requirements for UTRA/FDD Transceivers", *Proceedings of the Fourth International Symposium on Wireless Personal Multimedia Communications Conference*, September 2001, vol.1 pp197-202

[5] A. Loke, F. Ali, "Direct Conversion Radio for Digital Mobile Phones – Design Issues, Status, and Trends", *IEEE Transactions on Microwave Theory and Techniques*, vol. 50, no.11, November 2002

[6] R.G. Jensen, K.T. Christensen, E. Brune, "Programmable Baseband Filter for Multistandard Mobile Phones", *Analog Integrated Circuits and Signal Processing*, Kluwer Academic Publishers, 34, pp. 49-57, 2003

[7] U. Stehr, et al., "A Fully Differential CMOS Integrated 4th Order Reconfigurable GM-C Lowpass Filter for Mobile Communication", presented at IEEE International Conference on Electronics, Circuits & Systems, December 2003